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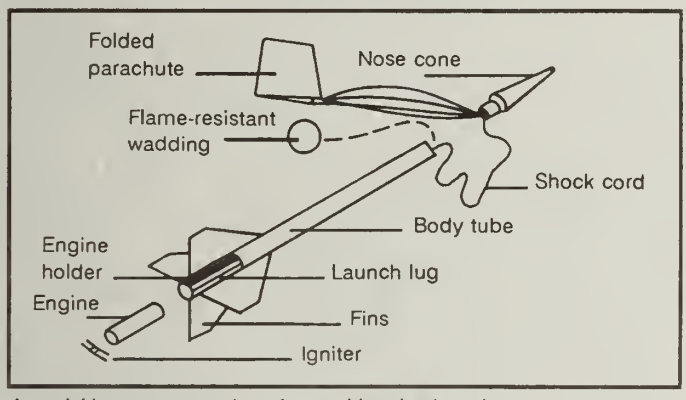
What are Computer Models and What Can They Tell Us About Waquoit Bay?

Waquoit Bay National Estuarine Research Reserve Science and Policy Bulletin Series

What is a Model Anyway?

Imagine a twelve year old child building rockets out of wood, glue, and cardboard. The models are supposed to look like real rockets; a few of them are built to scale - one inch on the model is equivalent to so many feet on the actual rocket. The companies that sell the model kits also sell engines that shoot the models high into the air.

So these model rockets look sort of like real rockets and behave sort of like real rockets. **And that is all that any model is - a representation of something that is real.**



A model is a representation of something that is real

A simple model of the biosphere

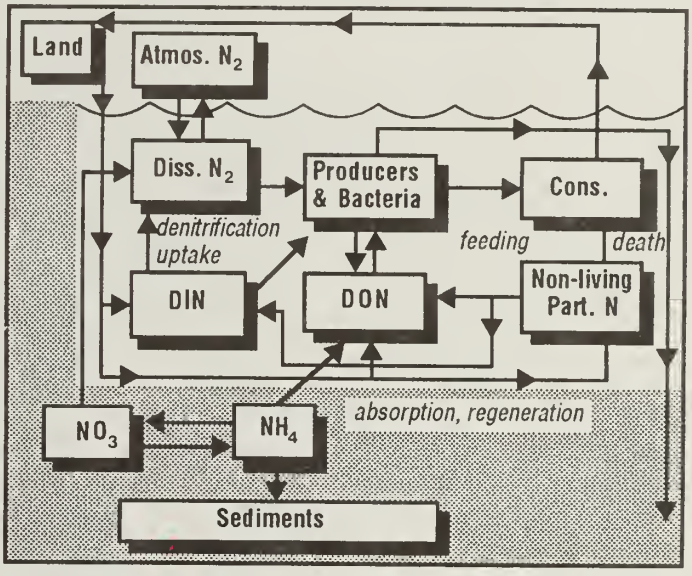
A physical model of the Earth might be a large, sealed terrarium with soil, plants, a pond, bacteria, fish, insects, and so on. This would be a very simplified representation of the Earth. If we wanted to understand the way nitrogen moves between the atmosphere, the land, and the ocean, we could measure the amount of nitrogen in each part of our model Earth at different times.

In addition to physical models, scientists use conceptual models; like physical models, they represent real systems. One example of a conceptual model is a list of rules that shows how we think nitrogen moves on the Earth:

1. **nitrogen moves from the atmosphere to plants, protists, and bacteria.**
2. **nitrogen moves from dead organisms to sediments.**
3. **nitrogen moves from plants to herbivores to carnivores.**
4. **nitrogen moves from animal waste to plants.**

Another type of conceptual model, which integrates these rules, is a flow diagram. In this case, the diagram would show the different places the nitrogen could be, and it would have arrows showing nitrogen moving from one place to another. If we thought that it moved from the land into the atmosphere faster than from the atmosphere into the oceans, we could make the arrows going from land to atmosphere thick, to indicate a faster rate of movement.

To describe more precisely the way we think nitrogen moves, we could use specific rates (eg pounds per year). We might also try to show how the different rates of movement depend



A flow diagram is another type of model

upon one another. Soon, instead of a series of sentences, our model would consist of a series of equations.

$$\frac{dx}{dt} = x\left[\frac{pI_0}{kz_1}(1 - e^{-kz_1})\,(N)\,(V) - R_0 e^{rT} - gZ\right]$$

How are Models Developed?

To explore how a model is developed and how it can be used, let us examine the modeling project at Waquoit Bay.

So, thinks the modeler, I want to understand how land use in the watershed affects nutrient concentrations and the ecosystem in Waquoit Bay. Hmm. Well, I had better divide this problem into parts, study the parts individually, and then put the pieces back together. Some of the pieces I need to study are:

1. *From where does groundwater flow into Waquoit Bay?*
2. *How do different land uses in this area (single family homes, agriculture, and industry) affect the groundwater?*
3. *How fast does the groundwater move?*
4. *How does the algae in the bay respond to different levels of nutrients?*
   Does this depend upon the time of year?
   Does it depend upon the amount of light?
   On the temperature?
5. *How do the fish and shellfish respond to changes in the algae populations?*

With this information, I can build a model (a relatively simplistic description of a real system) that says: so-and-so many houses combined with so-and-so many farms and so-and-so much light industry in these-and-those places should lead to groundwater with this concentration of nutrients entering the bay. The algae should then grow at thus-and-such a rate, and we should find this-and-that much algae in the bay at this-or-that time of year. Under those conditions, with weather patterns like these-or-those, we should find oxygen concentrations in the bay like this-and-that.

What if this model could really describe a system accurately? Ahh, what bliss. Say we want to know how the system will respond if we tweak it a little bit, change just one thing, or two things. Well, that would be no problem. We would just look at our list of rules or equations, and they would tell us what would happen. Hence the allure, the enticement, the lip-smacking sweetness that models exude.

Alas, for the unwary individual, taking this view of models leads inevitably to crestfallen frowns. All models are oversimplifications of the "real things" that they are supposed to represent. Indeed, ecological models are considerably less like the "real thing" than scale models of rockets. That is primarily for two reasons.

First, rocket builders understand how the machine is put together (after all, they have designed it), even though they may be wrong about how it will behave. Second, a rocket seems complex, but it actually has far fewer parts and works in a much more straight-forward fashion than the biosphere.

We are thus led to ask: "If models are so far removed from reality, why bother? Why produce these sets of rules and equations? Why should we care about them? What can these models tell us, and will that information help us to do our jobs better?"

What Can Models Tell Us?

Models as a Research Tool

One way in which the model is extremely useful is as a tool for a research group to give the members ideas about whether they are on the right track, to suggest ways in which they should modify their efforts, and to suggest fruitful avenues of cooperation.

During their study, scientists measure the quantities that the model predicts (eg, amount of algae in different parts of the bay). Suppose the model's predictions differ from observations made in the bay. That tells the modeler and his colleagues that they need to revise their ideas of how the system works. Perhaps a piece of the puzzle they thought was unimportant in fact needs to be considered.

Models as a Planning Tool

The model can also be useful to people who make decisions about land use regulation and therefore need information about how different land use patterns would affect the ecosystem in the bay. It is in this second area that misunderstandings about

Given this information	The model predicts these outcomes
land use patterns *(numbers and locations of houses, farms, bogs, industries, etc.)*	what nutrient concentrations should be in groundwater entering the bay at different points
weather patterns *(temperature, cloud cover, rainfall, wind speed and direction)*	what dissolved oxygen concentrations should be in different parts of the bay
how algae respond to different levels of nutrients *(how fast different species grow, how much oxygen they produce during the day)*	how much algae should be in different parts of the bay

Simplified summary of information needed by a model and predictions generated by the model

the abilities and constraints of models often arise.

Consider the question: "what will happen to Waquoit Bay if we build two hundred single family houses in these locations?" It is easy to understand the attraction of models that predict how different land use scenarios would impact the bay. Suppose the model were to predict that this development would cause the phytoplankton population to double. The critical point, and the one which is easy to miss, is the necessity of thinking about: "what do these predictions mean?" The answer to this question is not straight-forward, and its subtleties contribute to modelers' concerns about their products being misused.

There is certainly a chance that building these houses would cause the ecosystem to respond as the model predicts. It is difficult to define this probability precisely; is it 80%, 90%, 95% ? **Of course, the chance that the model's predictions are generally (or qualitatively) correct is much greater than the chance that they predict precisely how much algae will occur in a particular place on a particular date.**

The model does, however, have a number of strengths that enable it to give managers valuable information and insight about the general relationship of land use to the state of the bay. It will enable us to compare predictions from different land use scenarios, to compare the effects of a single change within an internally consistent framework, and there is a good chance that the model will accurately predict differences in resulting trends. So, while a prediction that phytoplankton production will double in response to a particular development scenario may not be quantitatively precise, it is nevertheless a useful result because the general pattern of significant phytoplankton increase is probably a sound prediction.

The reason that the model's predictions are particularly valuable is that the model affords us the ability to look at interactions and feedback loops within the system - checks and balances, positives and negatives which can lead to non-intuitive effects.

Predictions mean	Predictions do not mean
given a certain set of conditions (eg weather), defined by the user, there is reasonable chance (or risk) that the ecosystem will respond in a manner not too different from the model's predictions	under any conditions (eg weather), the ecosystem will respond exactly in accordance with the prediction
given two very different land use scenarios, there is good chance that the kinds of differences seen in the model's predictions for the two scenarios resemble the kinds of differences that would be observed in the ecosystem	there is a quantitatively precise risk that a particular development scenario will have a particular effect on the bay's ecosystem

What predictions from the model mean and what they do not mean

The model does not and will not yield *quantitatively precise* answers about how the bay's ecosystem will respond to different land use patterns. For example, where the model predicts a doubling of phytoplankton production in response to a particular development, we will probably see an increase that is less than twice or more than twice.

Like all models, the one being developed to describe the interactions between land use and ecosystem response in Waquoit Bay is a simplification of reality. We may not, and probably do not, understand all of the components and interactions occurring in the Waquoit Bay ecosystem. Therefore, the model

Advantages of the model	Disadvantages of the model
captures interactions and non-intuitive feedback effects	impossible to include all aspects of ecosystem function
enables us to lood at trends resulting from different land use scenarios	does not provide risk analyses or pat answers
captures the most important features of the system	requires a methodology for incorporating its results into a risk analysis

Advantages and disadvantages of computer models as planning tools

(our representation of how the actual ecosystem behaves) includes a number of reasonable assumptions.

However, the model tries to capture what is most important in determining the structure and function of the ecosystem. It attempts to show how the whole, complex, dynamic system works by looking at how several of the most critical components of the system work and interact.

Risk Analysis, Confidence Limits, and Food Poisoning

The difficulties facing managers who would like to use models such as the one being developed by the Waquoit Bay LMER, and for scientists advising them on the matter, arises in part from subtle differences between the questions resource managers ask and the questions that research scientists ask. When scientists evaluate the validity of a hypothesis, they look for 95% confidence. That is, data are considered to support a hypothesis only if there is less than a 5% chance that the results supporting the hypothesis occurred by chance.

Often, resource managers do not require this level of confidence. Rather, what is relevant is the degree of risk that a particular decision carries with it. "If we build those two hundred houses, what is the risk that the amount of algae in the bay will increase?" Even a fifty percent chance may be sufficient to decide against building the houses.

Ecologist Paul Ehrlich once polled a group of world experts on the subject of global warming. How many of you, he asked, think there is a ninety percent chance that global temperatures will continue to increase as a result of greenhouse gas emissions by humans? How many of you think there is an 80% chance? 70? 60? The most conservative scientists present indicated that they believed there was at least a 30% chance that human activities were leading to global warming. The most liberal estimated 90%. Even if we were to consider only the most conservative estimate, would we be willing to take a 30% chance? Would we eat in a restaurant if we knew there was only a 30% chance that our meal would contain arsenic?

Computer models like the one being developed by the Waquoit Bay LMER do not provide risk analyses or quantitatively precise predictions. This particular model may provide the best available holistic understanding of the ecosystem. The challenge is for resource managers to find a means for incorporating information generated by the model as a significant component in making decisions. ▪

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The Waquoit Bay National Esturine Research Reserve is part of the National Estuarine Research Reserve System, established by section 315 of the Coastal Zone Managment Act, as amended. Additional information about the System can be obtained from the Sanctuaries and Reserves Division, Office of Ocean and Coastal Resource Management, National Oceanic and Atmospheric Administration, U.S. Department of C ommence, 1825 Connecticut Avenue, N.W., Washington, DC 20235

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